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# Characteristic Study of Chip-on-Film Interconnection

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## ABSTRACT

Chip-on-film (COF) is a new technology after tape-automated-bonding (TAB) and chip-on-glass (COG) in the interconnection of liquid crystal module (LCM). The thickness of the film, which is more flexible than TAB, can be as thin as 44  $\mu\text{m}$ . It has pre-test capability, while COG hasn't. It possesses great potential in many product fabrication applications.

In this study, we used anisotropic conductive film (ACF) as the adhesive to bind the desired IC chip and polyimide (PI) film. The electric path was formed by connecting the bump on the IC and the electrode on the PI film via the conductive particles in the ACF. In the COF bonding process experimental-design-method was applied basing on the parameters, such as bonding temperature, bonding pressure and bonding time. After reliability tests of (1) 60°C/95%RH/100Hr and (2) -20°C ~70°C/ 30 cycles, contact resistance was measured and used as the quality inspection parameter. Correlation between the contact resistance and the three parameters was established and optimal processing condition was obtained. The COF samples analyzed were fabricated accordingly. The contact resistance of the COF samples was measured at varying temperature using the 4 points test method. The result helped us to realize the relationship between the contact resistance and the operation temperature of the COF technology. This yielded important information for circuit design.

**Key words:** Chip-on-Film (COF), Anisotropic Conductive Film (ACF), Polyimide (PI), Tape Automated Bonding (TAB), Chip-on-Glass (COG)

## 1. INTRODUCTION

COF (Chip-on-Film or Chip-on-Flex), as shown in figure 1, is the fabrication technology that currently applied in LCM (Liquid Crystal Module) of small panel. COF is developed after the Surface Mount Technology (SMT), TAB (Tape Automated Bonding), and COG (Chip On Glass) technology as shown in figure 2. The geometry of the COF is similar to that of TAB, but due to its substrate is of two-layer structure (Cu and polyimide), it is thinner, of higher density, better flexibility and high-temperature durable; not like TAB which is normally three-layer structure (Cu, adhesive, and polyimide). Compared with COG, COF has the features of lower contact resistance and available pre-test capability. This technique has

grown quickly and been applied on high-density, multi-functional LCM fabrication, such as mobile phone, PDA (Personal Digital Assistance). In addition, it is also applied to CSP (Chip Scale Package) [1]-[3] and multi-chip module [2]. Typical examples are the mobile phone products by Wintek Corporation as shown in figure 3. The corresponding pitches of ILB (Inner Lead Bonding) are 120  $\mu\text{m}$  and 80  $\mu\text{m}$ , respectively. Numerous local makers are developing this technology and are setting up production lines after Japan.

This study first searched for the optimal process parameters according to the results from reliability test. The COF samples were then fabricated accordingly. The contact resistance was measured under various different temperatures to understand the influence of the environmental temperature on the COF contact resistance.

## **2. BONDING METHODS OF CHIP-ON-FLEX**

COF is one of the Flip Chip Bonding technologies, and it uses flexible printed circuit board as the substrate. The COF bonding can be processed with ACF bonding, eutectic bonding, or soldering connection.

### **2.1 ACF process**

As presented in figure 4, ACF bonding is one of the main stream processes, and this method is based on the conductive particle which makes electrode connection between IC bump and electrode on flex. The binder not only can be used as an adhesive but also provides the necessary contractility to maintain the contact between the electrodes. In order to achieve the minimum contractility required for the conductivity of the contact provided by the binder, An Au coated polymer particle was chosen as the conductive particle instead of a pure metal one. This causes lower contractility which is needed for ACF binder. Furthermore, the TCE (Thermal Coefficient of Expansion) of polymer particle is similar to that of the ACF binder. As a result, under different temperature environments, the variation of the contractility is moderately minor as well as the variation of contact resistance. Because COF process is similar to COG and TAB-on-Glass processes, many LCM fabricators have developed in accordance with this trend.

### **2.2 Eutectic bonding [1]**

This process is achieved by heating the joints of IC chip and flex to form the eutectic bonding between Au and Sn, then protecting the joints by underfill. In the past, TCP (Tape Carrier Package) used eutectic process. However, due to the mid layer (adhesive) in this three-layer structure is not high temperature durable, punching a window for bonding area is unavoidable and the bonding lead's support substrate (PI) is removed. Finally, the ILB joints are protected by encapsulation. On the other hand, COF's substrate (flex) is two-layer structure without adhesive layer. Hence, it can endure high-temperature process like eutectic bonding. Since the COF process is similar to TCP process, many manufactures with TCP fabrication lines move towards this direction. This technology becomes another mainstream manufacturing procedure of COF.

### **2.3 Soldering [2]-[3]**

This is based on solder reflow. Connection is achieved by melting the joints on the electrodes of IC Solder bump and flex, and then fills the underfill. The disadvantage of this process is easy to form shortage resulted from melting connection so that it is not suitable for high-density connection.

### 3. EXPERIMENT

This experiment adopted the most commonly used ACF process in the LCM field.

#### 3.1 Materials preparation

Driver IC :

Chip Size: X=11.49 mm, Y=2.44 mm

Chip Thickness:  $400\ \mu\text{m} \pm 30\ \mu\text{m}$

Bump Size:  $50\ \mu\text{m} \times 110\ \mu\text{m}$

Bump Pitch:  $80\ \mu\text{m}$

Bump Height:  $25\ \mu\text{m}$

Bump Material: Au

Flex Substrate:

- Base film (Polyimide):  $22\ \mu\text{m}$  thick

- Conductor(Copper):  $12\ \mu\text{m}$  thick, coated with gold

- Insulator (Solder resistor):  $10\ \mu\text{m}$  thick

ACF:

- Binder:  $25\ \mu\text{m}$  thick, thermal set

- Conductive particle (Resin coated with gold):  $5\ \mu\text{m}$

#### 3.2 ACF properties measurement

In order to improve the quality of connection and further investigate the characteristics of the connection; besides having the bonding parameters suggested by ACF maker, we measured the curing temperature and Tg value from DSC (Differential Scanning Calorimeter) and TMA (Thermomechanical Analyzer) to fully understand the characteristics of the ACF.

The ACF's DSC analysis is shown in figure 5. The curing reaction was started when temperature was higher than  $124^{\circ}\text{C}$ . Bonding time had to be long enough for fully curing. Generally, the bonding temperature was set at  $180^{\circ}\text{C}\sim 210^{\circ}\text{C}$  to increase the throughput.

The ACF's TMA analysis is shown in figure 6. The curing condition was set at  $180^{\circ}\text{C}$  for 5 sec. The resultant Tg was  $131^{\circ}\text{C}$ . Some ACF samples were cured at various temperatures, i.e.  $160^{\circ}\text{C}$ ,  $170^{\circ}\text{C}$ ,  $180^{\circ}\text{C}$ ,  $190^{\circ}\text{C}$ ,  $200^{\circ}\text{C}$  and  $210^{\circ}\text{C}$ . The Tg results are shown in figure 7. When curing temperature was higher than  $180^{\circ}\text{C}$ , the Tg achieved a stable value which was around  $130^{\circ}\text{C}$ . This means that bonding temperature needs to be set at temperature higher than  $180^{\circ}\text{C}$  to ensure enough curing degree. It is also discovered that the COF product under an environmental temperature higher than Tg shows

significant variation on its contact resistance.

### 3.3 Bonding accuracy measurement

Bonding accuracy affects the contact resistance of high-density connection. Poor accuracy causes random data and serious experimental deviation. It is difficult to check the accuracy due to poor transparency of the flex. Thus, X-ray or ultrasound measurement must be applied to check the connection. Figure 8 shows the X-ray photograph of the bonding result of the COF sample from the backside. It is clear to see that the leads of the flex have been accurately bonded to the bumps of the chip.

### 3.4 Bonding procedure

The process of COF bonding material by ACF is listed below:

Cleaning: Cleaning the surface of flex by IPA (isopropyl alcohol) or acetone

Lamination (Temporary bonding): Attaching ACF to Flex by proper temperature and pressure.

Removal of the separator: Peel off the separator of ACF

Alignment: CCD camera with image processor is used to capture and align the image of IC and flex.

Apply heat and pressure (Bonding): Impose high temperature and pressure on IC to cure ACF.

Remove pressure: The COF process is done after removing the thermode.

### 3.5 Experimental design

The parameters in this experiment included bonding temperature, bonding pressure and bonding time. The temperature was set at 170°C, 190°C, and 210°C, respectively. The pressure was set at 30 g/bump, 50 g/bump, and 70g/bump. The time was set at 5 sec, 10 sec, and 15 sec. 27 combinations were obtained by all-factor experimental method. 6 samples were made for each parameter set. These samples were tested to realize their reliability upon thermal cycling from -20 to 70°C for 30 cycles and high temperature humidity at 60°C, 95%RH for 100Hr. All these reliability tests follow IEC 60068-2-3 standards. According to these optimal parameters, several COF samples were made and the contact resistance of each sample was measured under different temperature environments. The relationship between the contact resistance and the temperature variation had been established. In the meantime, the I-V curve of the joints was determined

### 3.6 contact resistance measurement

Figure 9 shows the COF's circuit design for electrical measurement and the equivalent circuit. Since  $I_{\text{sense}}$  is negligible, one has

$$V/I = R_2,$$

where  $R_2$  is the contact resistance from bump-2 to the electrode of flex through ACF. The electrical resistance of the copper electrode is relatively small when compared to the ACF contact resistance, so it can be neglected.

## 4. RESULT AND DISCUSSION

#### 4.1 Contact resistance after COF bonding

Figure 10 shows bonding force effect on the contact resistance of the COF samples cured at various temperatures before reliability test. The respective curing conditions are (a) 170°C, (b) 190°C, and (c) 210°C. As can be seen the contact resistance is lower when the bonding force is larger, the bonding temperature higher, and the bonding time longer.

Figure 11 shows SEM photographs of the COF samples cured under three different conditions (a) 170°C/5sec/(30g/bump), (b) 210°C/5sec/(30g/bump), and (c) 210°C/15sec/(70g/bump). The photographs obviously indicate the gap between the leads of flex and the bumps of IC chip to be the largest for condition (a), second largest for condition (b), and the smallest for condition (c). The corresponding contact resistance of the sample shown in figure 11(a) is the largest, followed by (b), and (c) is the lowest. Comparing figure 11 (a) with 11 (b), it is learned that higher bonding temperature results to higher curing extent for the binder, the binder hence becomes stiffer. After the bonding process, the conductive particle only recoils a little, the gap is small, and then the contact resistance is relatively low. As learned from figures 11(a), (b), and (c), the gap is smaller and the contact resistance lowers, when the bonding force is larger, bonding temperature higher, and bonding time longer.

#### 4.2 Contact resistance after thermal cycling test

Figure 12 shows bonding force effect on the contact resistance of the COF samples cured at various temperatures after thermal cycling test (-20°C~70°C/ 30 cycles). The respective curing conditions are (a) 170°C, (b) 190°C, and (c) 210°C. As can be seen the contact resistance is lower when the bonding force is larger, bonding temperature higher, and bonding time longer. The variation of contact resistance is relatively small after the thermal cycling when comparing figure 10 against figure 12. This indicates that the ACF bonding has been barely affected by thermal cycling.

#### 4.3 Contact resistance after high temperature humidity test

Figure 13 shows bonding force effect on the contact resistance of the COF samples cured at various temperatures after the high temperature humidity test (60°C/95%RH/100Hr). The respective curing conditions were (a) 170°C, (b) 190°C, and (c) 210°C. As shown in figures 13, those samples cured at the higher temperatures or longer curing time, the contact resistance decreased with the increase of bonding force, except for the sample bonded at 170°C for 5 sec as shown in figure 13(a), the contact resistance increases with the increase of the bonding force. This sample which bonded at 170°C for 5 sec may be due to poor curing of the binder that results to weak structure and poor adhesion. Since larger bonding force induces larger bouncing force, larger gap could then be resulted after the high temperature humidity test. This in turn results to higher contact resistance.

Comparing figure 13 against 10, it can be seen that the contact resistance of all the COF samples became higher after the high temperature humidity test. This was especially true for that cured at 170°C for 5 sec. This clearly indicates high temperature humidity test to have great impact on the ACF bonding, especially when the resin is not fully cured.

According to the 27 sets of experiment, it was realized that the COF sample fabricated at 210°C for 15 sec with a bonding force of 70g/bump exhibited the lowest contact resistance. Its contact resistance had been barely affected after the reliability test. Its fabrication conduction was then decided to be optimal. The subsequent COF samples were then prepared under this chosen condition. Their interconnection characteristics were investigated and given in the following section.

#### 4.4 Contact resistance at various temperatures

Figure 14 shows the contact resistance of the COF samples at different environmental temperatures. As seen in figure 14, the contact resistance increased with the increase of temperature. This may be attributed to the fact that the CTE of the ACF binder is smaller than that of the Au bump and conductive particle. This CTE mismatch caused reduction of the contact area between the IC bump and particles or between the electrode and particles, which would increase the contact resistance.

When the temperature was higher than 130°C, the contact resistance increased with the increase of temperature at a higher rate. This is because the binder was softened at temperature above its  $T_g$ . The softened structure would be more difficult to hold the conducting parts in good contact. Furthermore, the CTE value of the binder increased with the increase of temperature at a higher rate. Larger thermal mismatch for the binder with the conducting parts caused more serious reduction in their contact area. This, in turn, resulted to a rapid increase in the contact resistance.

#### 4.5 IV curve measurement

Figure 15 shows the I-V curve result of the COF joints. The I-V curve shows a linear relationship as the current is smaller than 0.09A, indicating that the joint is an ohmic contact.

### 5. CONCLUSION

The impact of thermal cycling test was quite small on the contact resistance of COF joint. Whilst, the impact of high temperature humidity was significantly large.

Optimal process parameters were determined according to the results from high temperature humidity test. When bonding temperature ( $\geq 180^\circ\text{C}$ ) and bonding time ( $\geq 5$  sec) were fixed, the contact resistance become smaller when the bonding force increased. Either higher bonding-temperature or longer bonding time can result to higher degree of curing for the resin. In order to have a high throughput, bonding temperature can be increased to shorten the bonding time. To prevent resin damage, bonding time can be increased to improve the desired extent of curing even at lower bonding temperature.

The contact resistance of the COF sample obtained according to the optimal process parameters was quite low (around  $0.1\ \Omega$ ) and it was ohmic contact. The variation of the contact resistance after reliability test was quite small (below  $0.02\ \Omega$ ). Even when the operation temperature is as high as  $140^\circ\text{C}$ , the contact resistance is still small (around  $0.18\ \Omega$ ). The electrical characteristics of the COF samples were stable and excellent.

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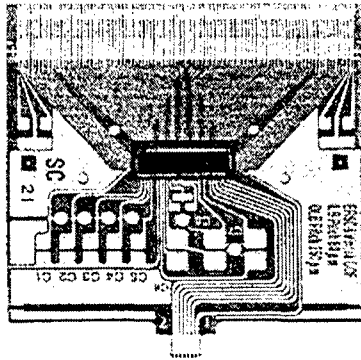
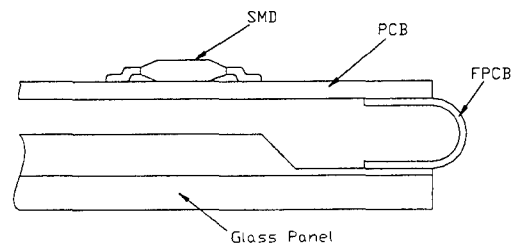
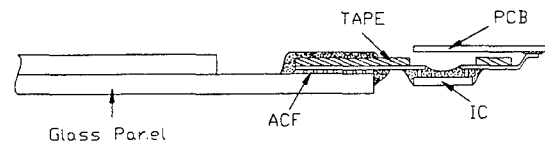


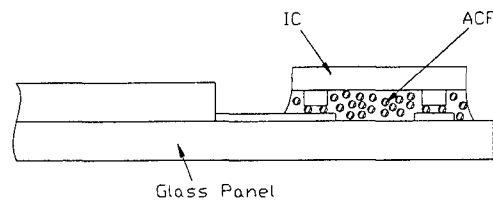
Figure 1. COF sample developed by Wintek and ITRI ERSO. The pitch is  $80\ \mu\text{m}$  and film thickness is  $44\ \mu\text{m}$ .



(a)



(b)



(c)

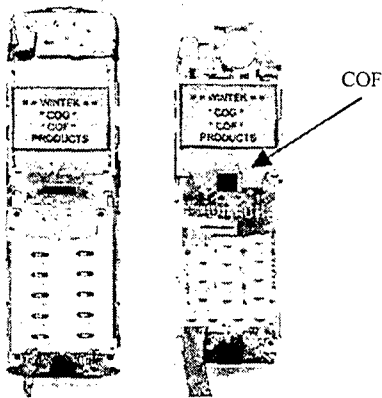
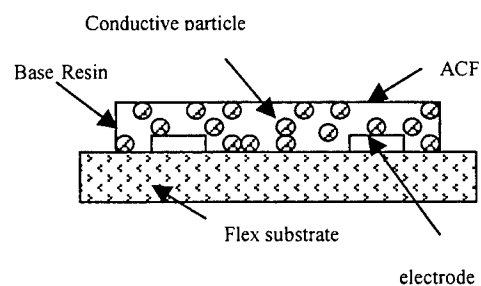


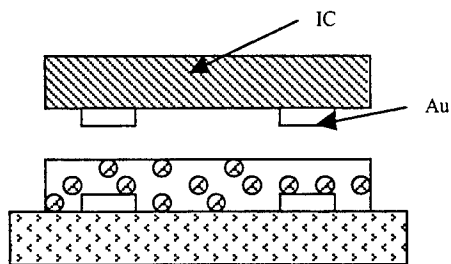
Figure 3. COF mobile phones by Wintek. The pitches are  $120\ \mu\text{m}$  (left) and  $80\ \mu\text{m}$  (right).

Figure 2. Three kinds of LCM packaging technology: (a) Surface Mount Technology (SMT), (b) Tape Automated Bonding (TAB), and (c) Chip on Glass (COG).

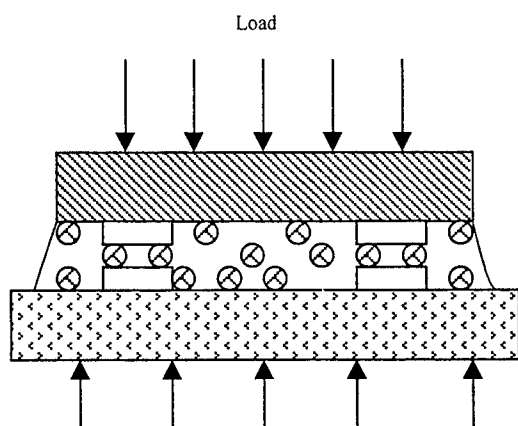




(a)



(b)



(c)

Figure 4. ACF process:

(a) Lamination (Temporary bonding): Impose enough pressure and temperature to attach ACF on flex substrate, (b) Alignment: Align between IC and flex substrate, and (c) Bonding: Apply high temperature and pressure through IC to cure the ACF.

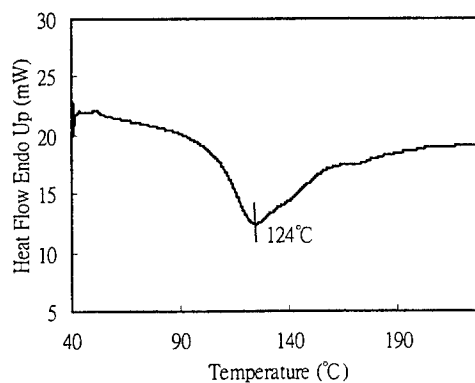


Figure 5. DSC result of the ACF. The ramp rate is 10°C/min.

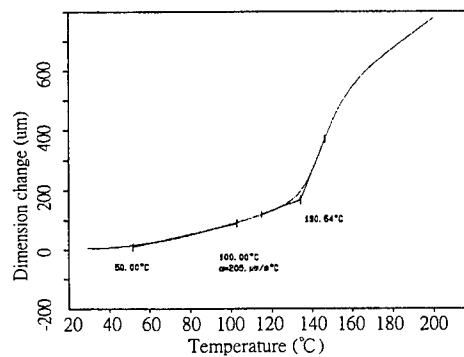


Figure 6. TMA analysis of the ACF, which had been cured at 180°C for 5sec.

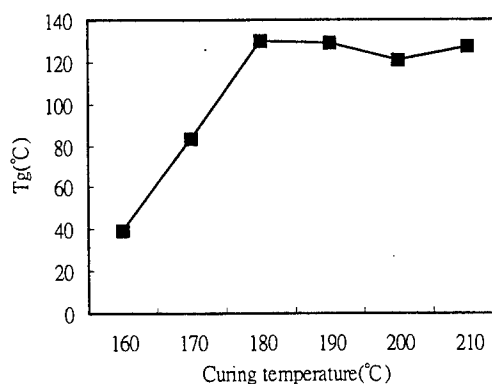


Figure 7. Effect of curing temperature on the Tg of the studied ACF.

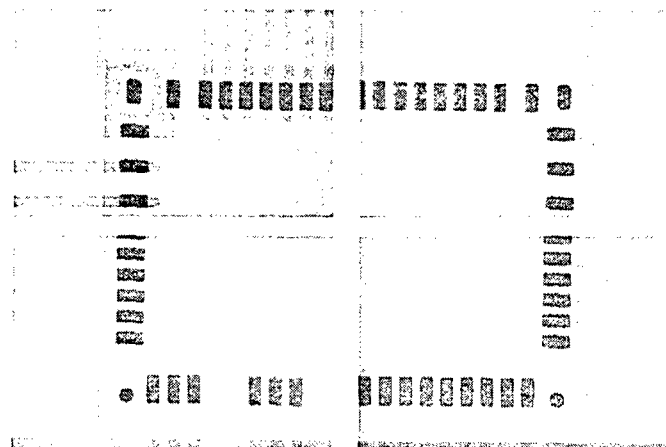


Figure 8. X-ray inspection of the backside of COF sample.

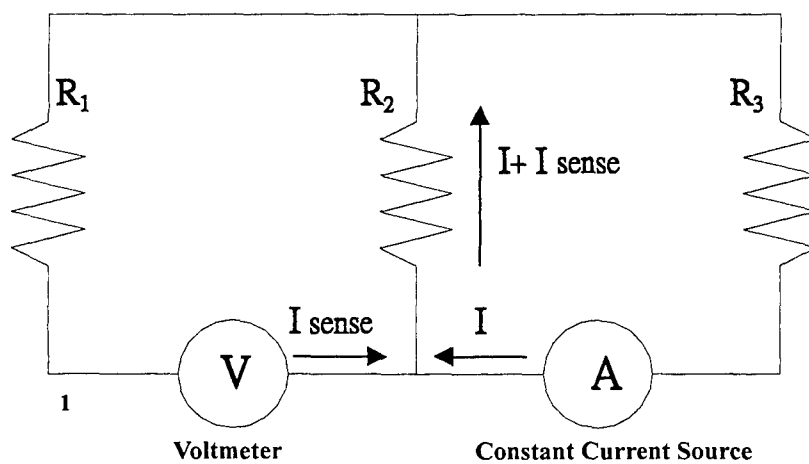
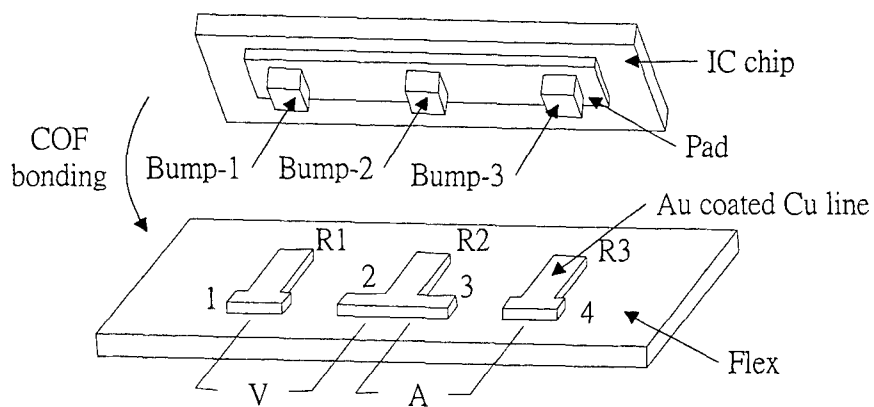


Figure 9. Schematic illustration of the  $R_2$  contact resistance measurement by using the 4 points test method and its corresponding circuitry.

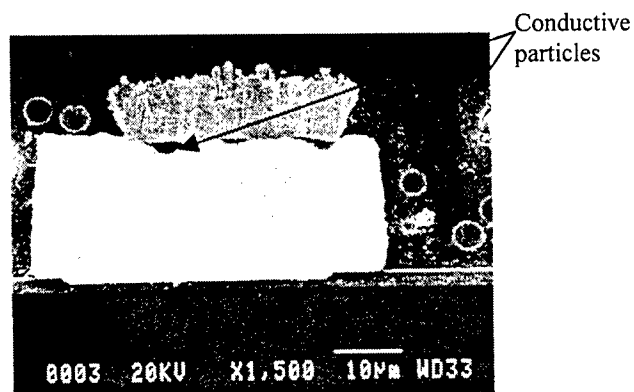
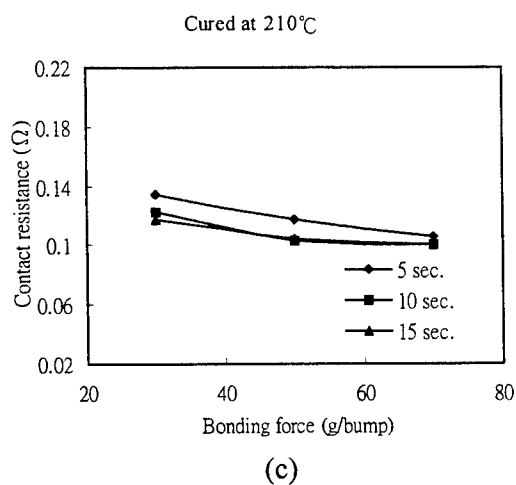
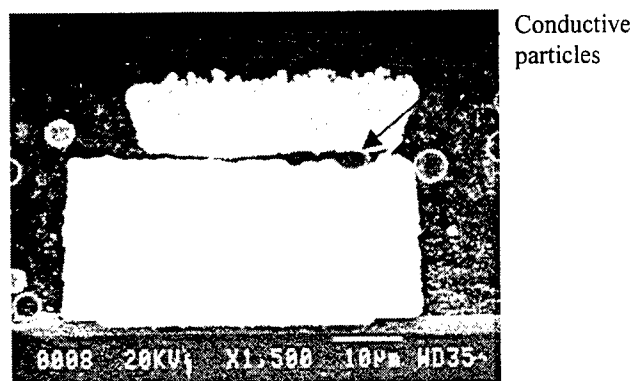
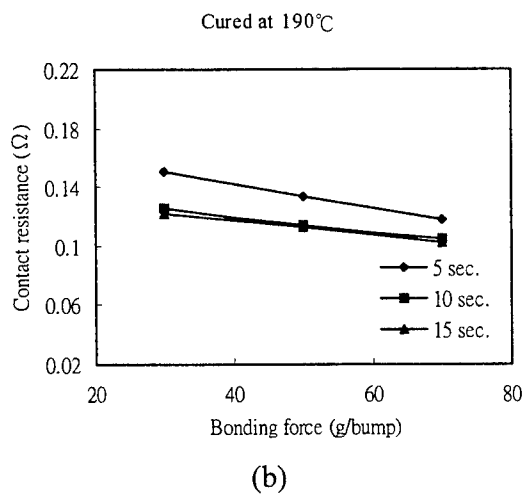
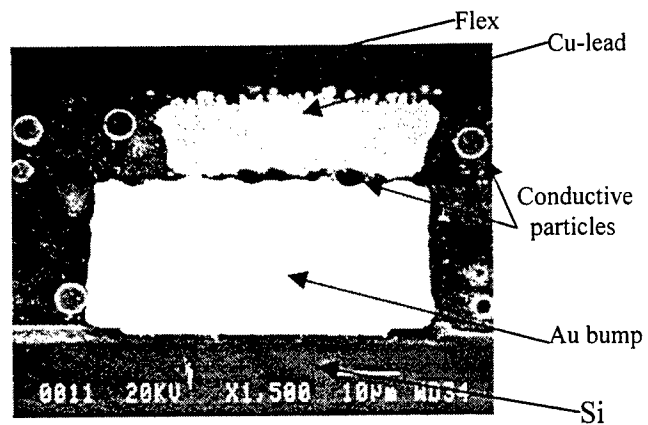
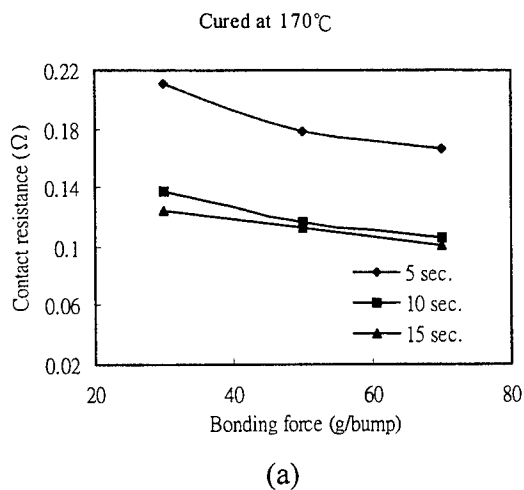


Figure 10. Bonding force effect on the contact resistance of the COF samples cured at various different temperatures before the reliability test.

Figure 11. SEM photographs of the COF samples cured under these different condition (a) 170°C/5sec/(30g/bump), (b) 210°C/5sec/(30g/bump) and (c) 210°C/15sec/(70g/bump)

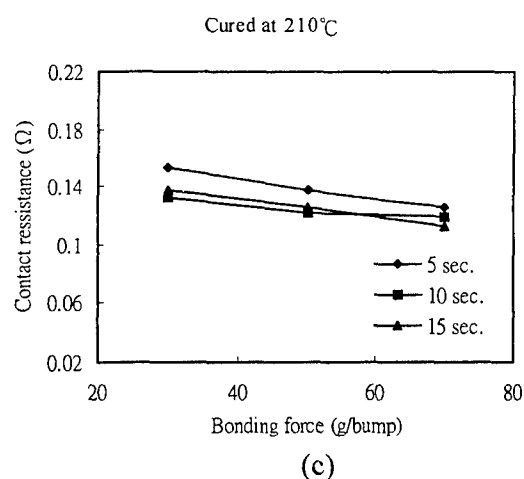
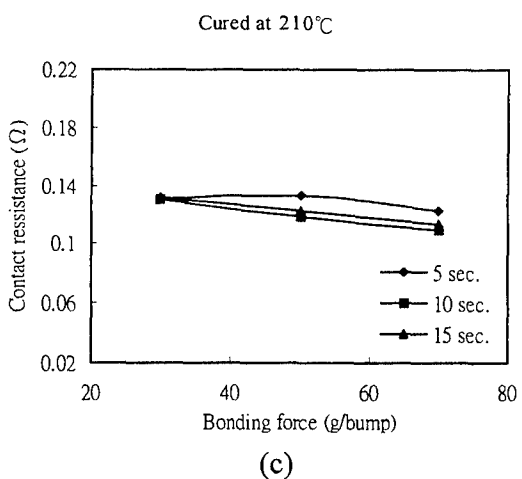
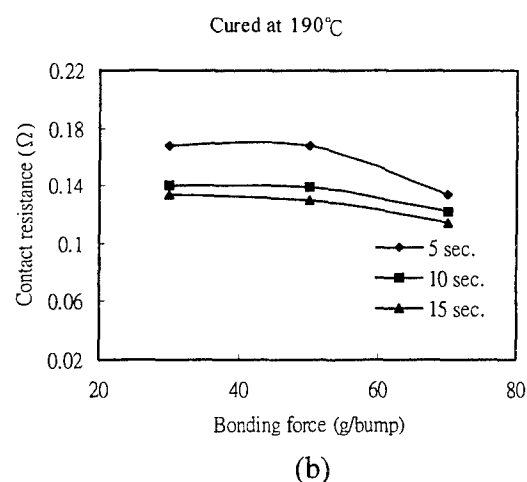
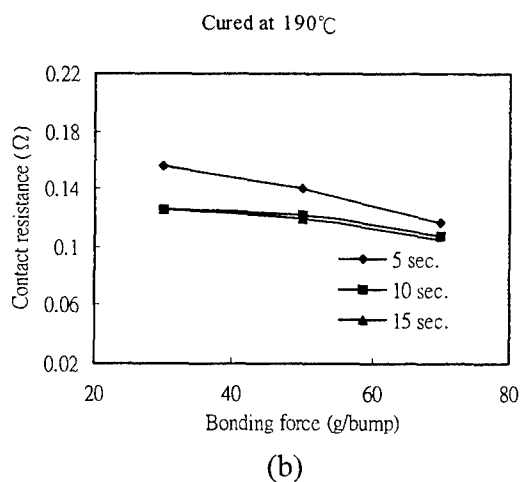
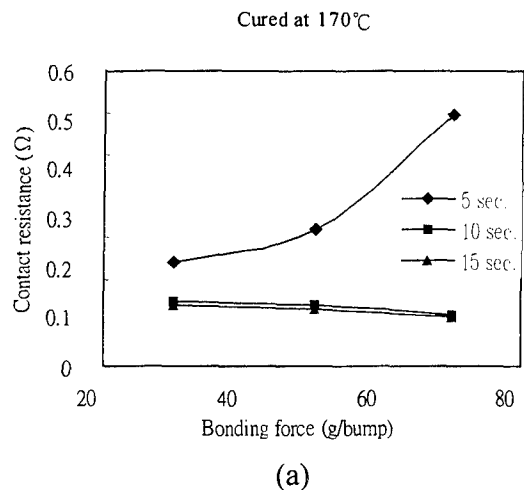
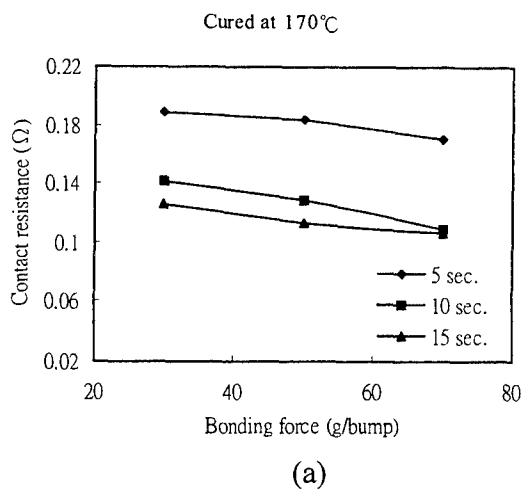


Figure 12. Bonding force effect on the contact resistance of the COF samples cured at various different temperatures after the thermal cycling test from -20°C~70°C for 30 cycles.

Figure 13. Bonding force effect on the contact resistance of the COF samples cured at various different temperatures after the high temperature humidity test at 60°C, 95%RH for 100hrs.

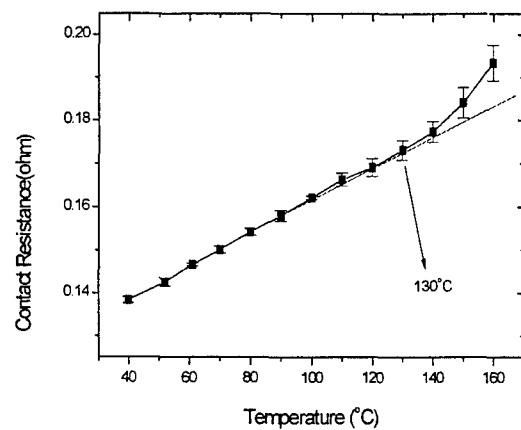


Figure 14. Contact resistance measured at various different temperatures.

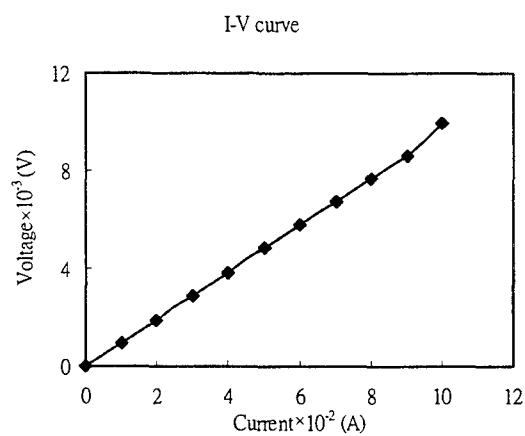


Figure 15. I-V curve of the resultant COF sample. The nearly straight line clearly indicates its ohmic contact characteristic

